

Search for Anomalous Production of Events with a W or Z Boson and Additional Leptons

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Abstract

We present a search for anomalous production of events containing a W or Z boson and additional leptons down to a low p_T threshold of 2-3 GeV. We are sensitive to clusters of leptons, or “lepton jets.” The search uses data corresponding to 5.1 fb^{-1} of integrated luminosity from $p\bar{p}$ collisions at a center-of-mass energy of $\sqrt{s} = 1.96 \text{ TeV}$. We find no indications of non-standard-model phenomena. Limits are set for a dark-matter inspired model of supersymmetric dark sector Higgs production.

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1 Introduction

In the standard model (SM) of particle physics, the mass of the Higgs boson is constrained to be larger than 114.4 GeV by the LEP experiments [1]. If the Higgs has evaded detection via non-standard decays, however, this limit can be avoided. There are various proposals for such a *hidden* Higgs sector in the literature in the context of the NMSSM [2], little Higgs models [3], R-parity violating MSSM [4], and others. One of the recent promising proposals involves the phenomenology of light supersymmetric hidden sectors [5] where the lightest visible superpartner, the equivalent of the LSP in the MSSM, is allowed to cascade into a hidden sector. The existence of such sectors has been further motivated by recent observed astrophysical anomalies [6] which may be signatures of dark matter annihilations [7] or decays into a light hidden sector [8]. Ref. [9] presents a model of Higgs decay to a light hidden sector resulting in events with a high multiplicity of leptons. Due to this high multiplicity the momenta of the leptons would tend to be low, predominantly below 20 GeV, and these events would not have been previously identified.

In this paper we present a search for the anomalous production of W and Z bosons in association with additional leptons with p_T down to 3 GeV for muons and 2 GeV for electrons. We present our results as a limit on a model that is representative of these theories, described in Ref. [9].

2 Analysis Strategy

The analysis uses the W and Z samples, selected via the high- p_T electron and muon triggers, which are well understood. We then develop specialized tools to identify low- p_T electrons and muons. We use these tools to obtain the $W/Z +$ lepton multiplicity distributions. We compare these expected and observed multiplicity distributions of additional leptons in W/Z events.

3 Event Selection

The base sample for the analysis is inclusive W 's and Z 's. We use the standard CDF selection criteria to identify hard (> 20 GeV) electrons and muons, with the additional requirement that hard muons have silicon hits. We look at three types of trigger leptons: electrons, muons in the CMUP detector, and muons in the CMX detector.

We validate the W samples using the kinematic plots in Figures 1, 2, and 3. Shown are the p_T of the trigger lepton, the missing energy in the event (\cancel{E}_T), the total transverse energy of every object in the event (H_T), and the W transverse mass.

We validate the Z samples using the kinematic plots in Figures 4, 5, and 6. Shown are the p_T of the two trigger leptons, the total transverse energy of every object in the event (H_T), and the dilepton mass. No significant discrepancies are observed.

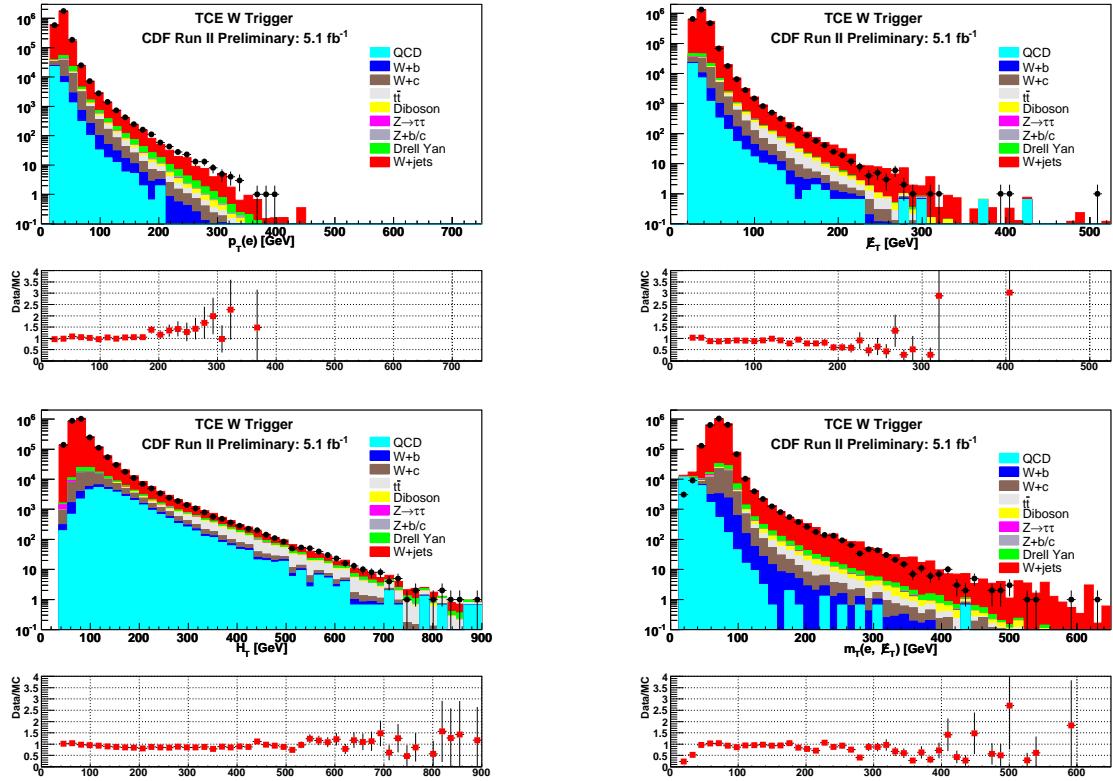


Figure 1: W validation plots, electron trigger: p_T of the highest- p_T good electron, E_T and H_T in the event, M_T of electron and E_T . There are cuts requiring $E_T > 25$ GeV and $m_T > 20$ GeV.

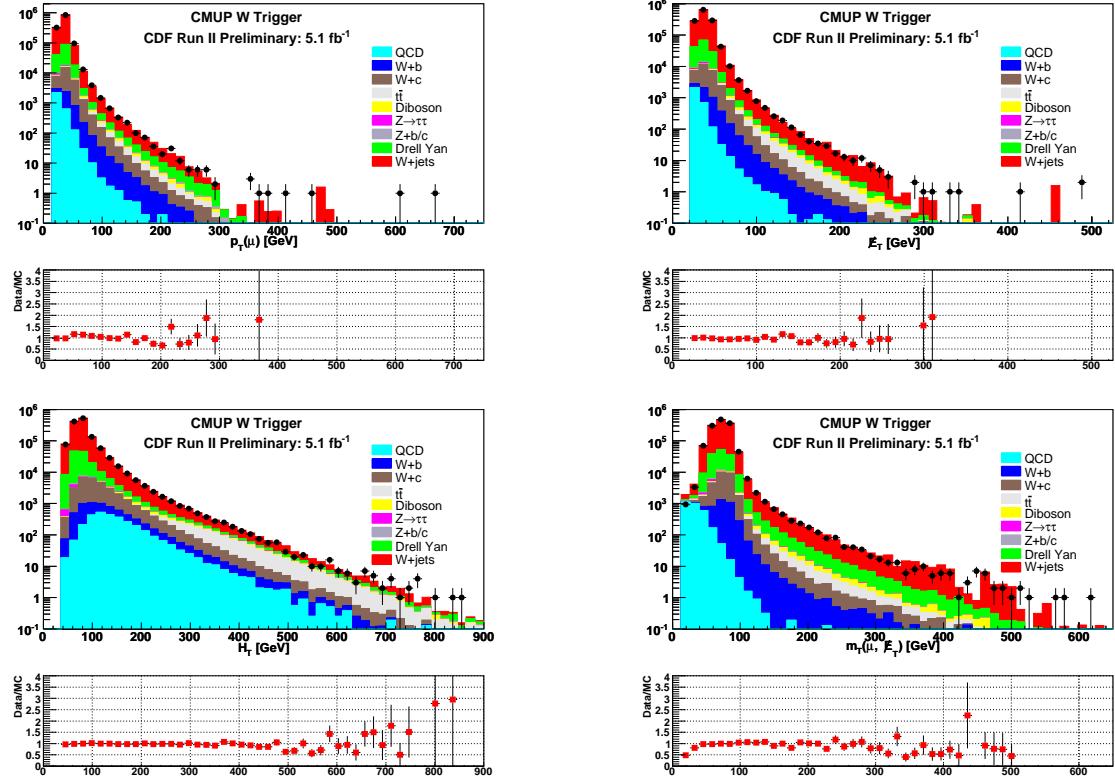


Figure 2: W validation plots, CMUP trigger: p_T of the highest- p_T good muon, \cancel{E}_T and H_T in the event, M_T of the good highest- p_T muon and \cancel{E}_T . There are cuts requiring $\cancel{E}_T > 25$ GeV and $m_T > 20$ GeV.

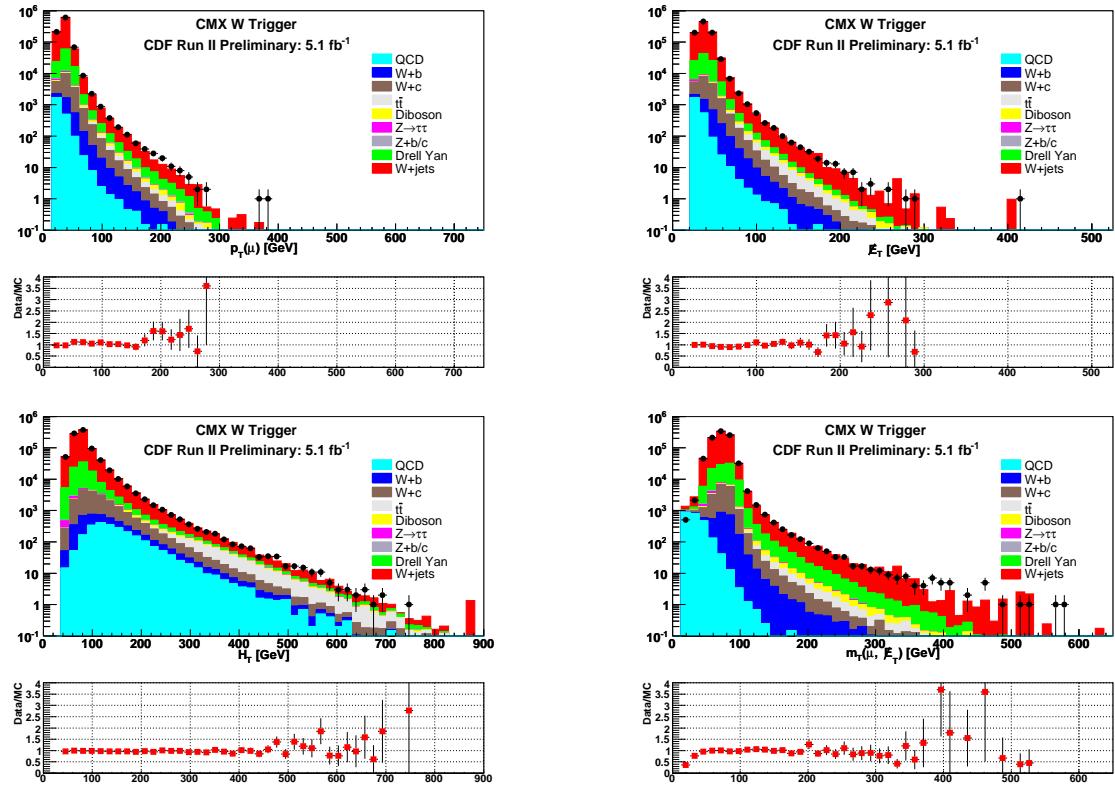


Figure 3: W validation plots, CMX trigger: p_T of the highest- p_T good muon, \cancel{E}_T and H_T in the event, M_T of the good highest- p_T muon and \cancel{E}_T . There are cuts requiring $\cancel{E}_T > 25$ GeV and $m_T > 20$ GeV

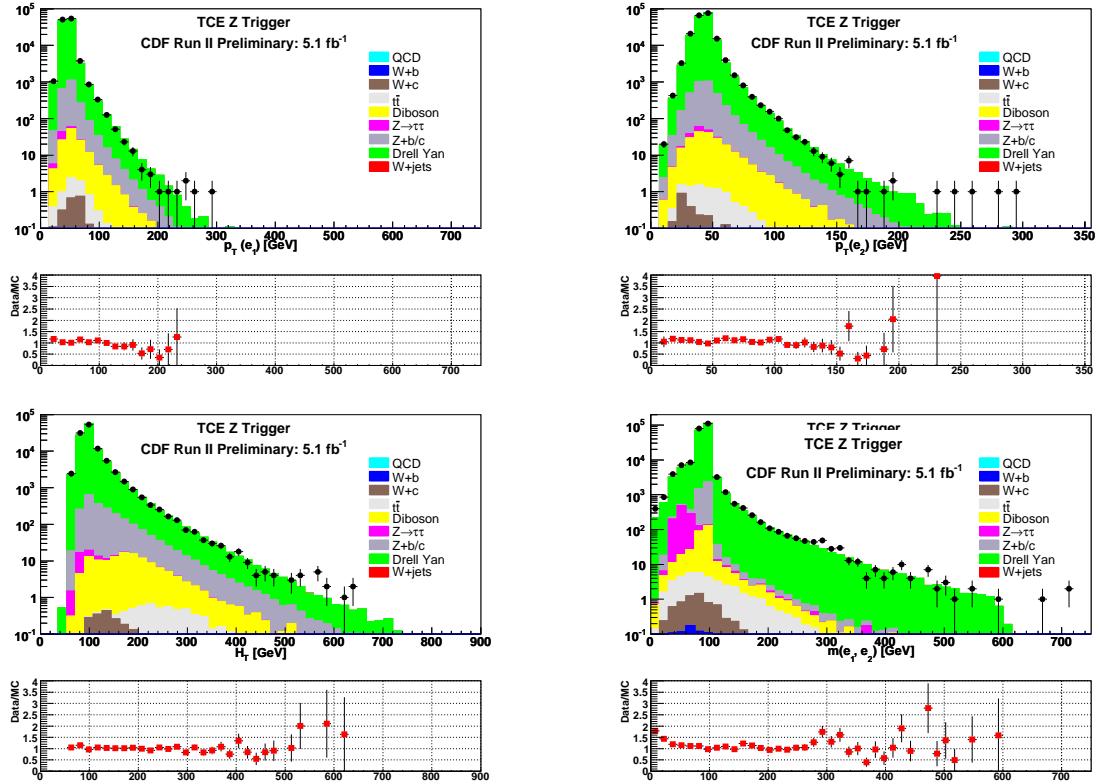


Figure 4: Plots of e-triggered Z events: the p_T of the two leading electrons, the H_T in the event, and the dilepton mass. In all the plots except the mass plot, there is a cut that the dilepton mass is between 76 and 106 GeV.

4 Soft Lepton Identification

4.1 Soft Electrons

We identify soft electrons using a likelihood-based method. This likelihood is trained completely on data. We use identified photon conversions as a training sample of real electrons. We use all non-electron tracks (removing photon conversions and any event with a hard electron or a heavy flavor jet) as the background sample. The efficiency and fake rate of this likelihood is shown in Figure 7.

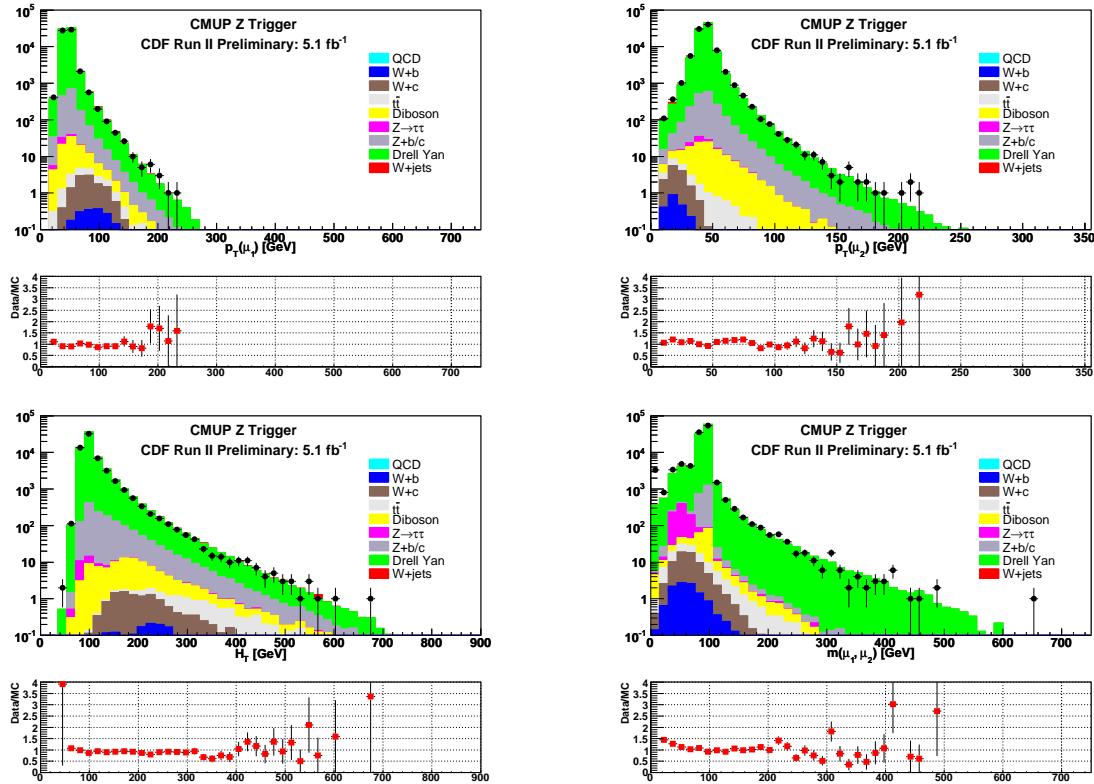


Figure 5: Plots of CMUP μ -triggered Z events: the p_T of the two leading electrons, the H_T in the event, and the dilepton mass. In all the plots except the mass plot, there is a cut that the dilepton mass is between 76 and 106 GeV.

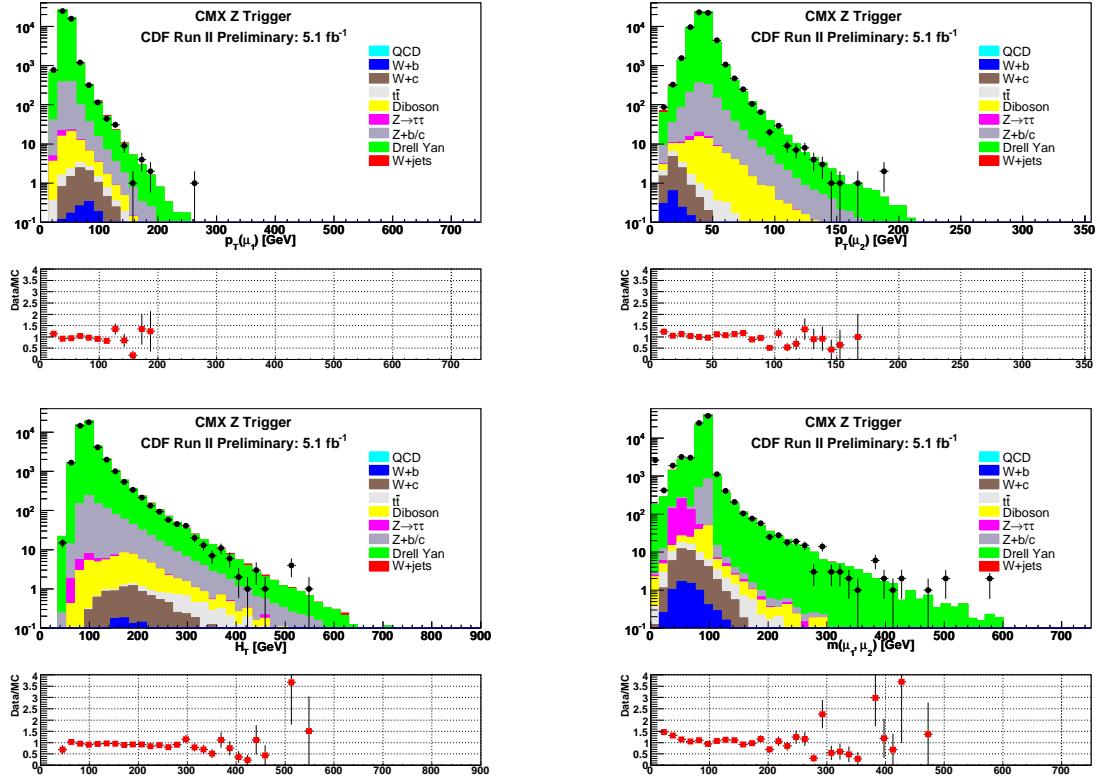


Figure 6: Plots of CMX μ -triggered Z events: the p_T of the two leading electrons, the H_T in the event, and the dilepton mass. In all the plots except the mass plot, there is a cut that the dilepton mass is between 76 and 106 GeV.

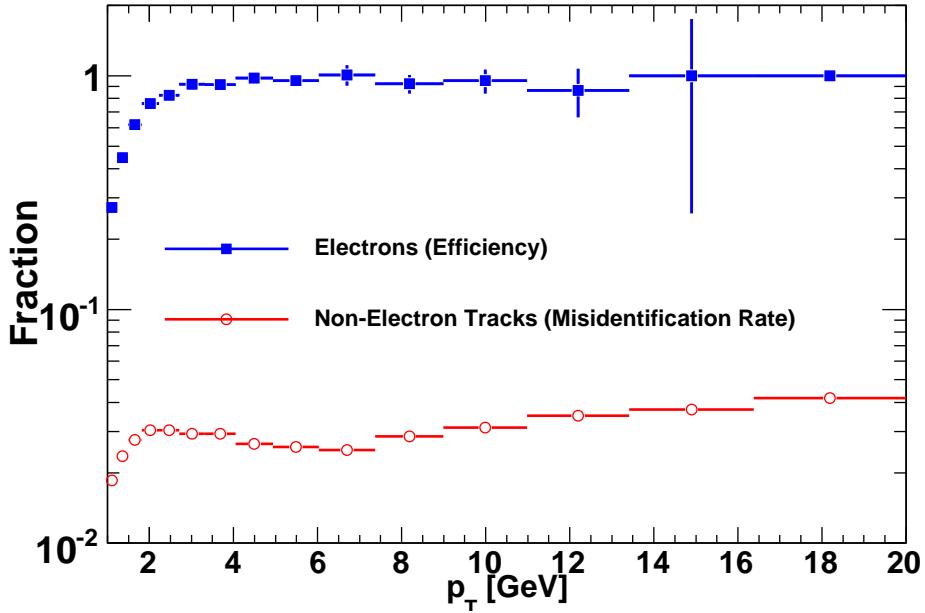


Figure 7: Comparison of the ID rate for real and fake electrons as a function of p_T .

4.2 Soft Muons

We use a soft muon identification algorithm based on the χ^2 of the track-stub matching variables for muon candidates. We measure the efficiency of this method using reconstructed $J/\psi \rightarrow \mu^+\mu^-$ decays to obtain pure μ samples. The misidentification rates of π and K are measured in $D^{*+} \rightarrow D^0\pi^+$ decays where D^0 decays as $D^0 \rightarrow K^-\pi^+$. Similarly, the p misidentification rate is measured in $\Lambda^0 \rightarrow p\pi$.

The efficiencies for each particle type are plotted in Fig. 8 as a function of p_T . Note that for all particles except for muons, the “efficiency” is actually the rate that the particle is *misidentified* as a muon. We see strong separation between muons and backgrounds.

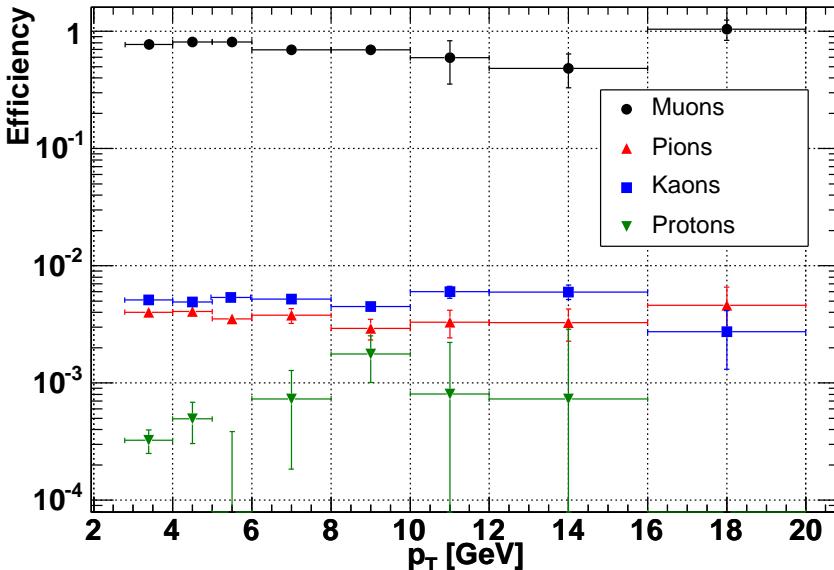


Figure 8: Identification efficiency as a function of p_T for μ , π , K , and p . For the case of the μ , this is the rate at which real muons are identified. For the other species, it is the rate that the particle is misidentified as a muon.

5 Background Prediction

5.1 QCD Background

Multi-jet events may emulate the signature of a W event. For example, there may be E_T arising from the energy mismeasurement of one jet while the other jet in the event mimics an electron.

We obtain the number of events that arise from QCD by fitting the E_T distribution of the data using two templates: an electroweak template obtained from $W +$ jets, $Z +$ jets and diboson Monte Carlo, and a QCD template obtained from selecting jets that have similar kinematics to our electron trigger. After we obtain the number of QCD events in this sample,

we extrapolate this number to the W signal region with $E_T > 25$ GeV. We scale the Monte Carlo electroweak contribution and the data-derived QCD template to the result obtained from the E_T fit in the inclusive W sample.

5.2 Heavy Flavor Fraction

Leptonic decays of heavy flavor is a significant background contribution to the soft leptons that we look for. In order to properly scale this background, we perform a simultaneous fit of p_T^{rel} and σ_{d_0} templates for heavy flavor, light flavor, and Drell-Yan processes to the data. We use the scale factors found with this fit to scale our MC templates.

5.3 Normalization of Soft Lepton Multiplicities

The heavy flavor fit described in Section 5.2 normalizes all of the data to the $W/Z+\mu$ bin, but there is still a mismatch in the $W/Z+e$ bin, which is also expected to be dominated by Standard Model processes. This mismatch is expected to be due to mismodeling of the number of photon conversions in the MC.

The difference between the predicted and observed numbers in the W/Z plus exactly one electron bin is measured, and is used as a systematic uncertainty for the normalization of all other MC with at least one additional identified electron.

6 Results

Figures 9 and 10 show the multiplicity of additional electrons and muons in W and Z events, with the Standard Model expectation, the benchmark model expectation, and the observed data overlaid. The two-dimensional histogram of N_μ vs. N_e is presented in slices of N_e for ease of viewing. Good agreement with the standard model expectation is observed across the distributions.

This model has a cross-section of 389 fb to produce a leptonic W or Z plus a Higgs. We set a limit of $0.312 \times \sigma$, or 112 fb, at 95% credibility. We can rule out the model at the standard cross section at a confidence level of 99.7%. Both of these limits are set using the MCLIMIT code[10].

7 Conclusions

We have performed a broad search for additional electrons and muons with p_T above a low threshold (3 GeV for muons and 1 GeV for electrons) in W and Z events. The signature of multiple leptons is common in many models of new physics with light mass scales and couplings to the Electroweak sector, including NMSSM [2], little Higgs models [3], and R-parity violating MSSM models [4].

We observe no excess over the predicted Standard Model background. We set a limit on a hidden-sector dark Higgs model as a representative of this class of models.

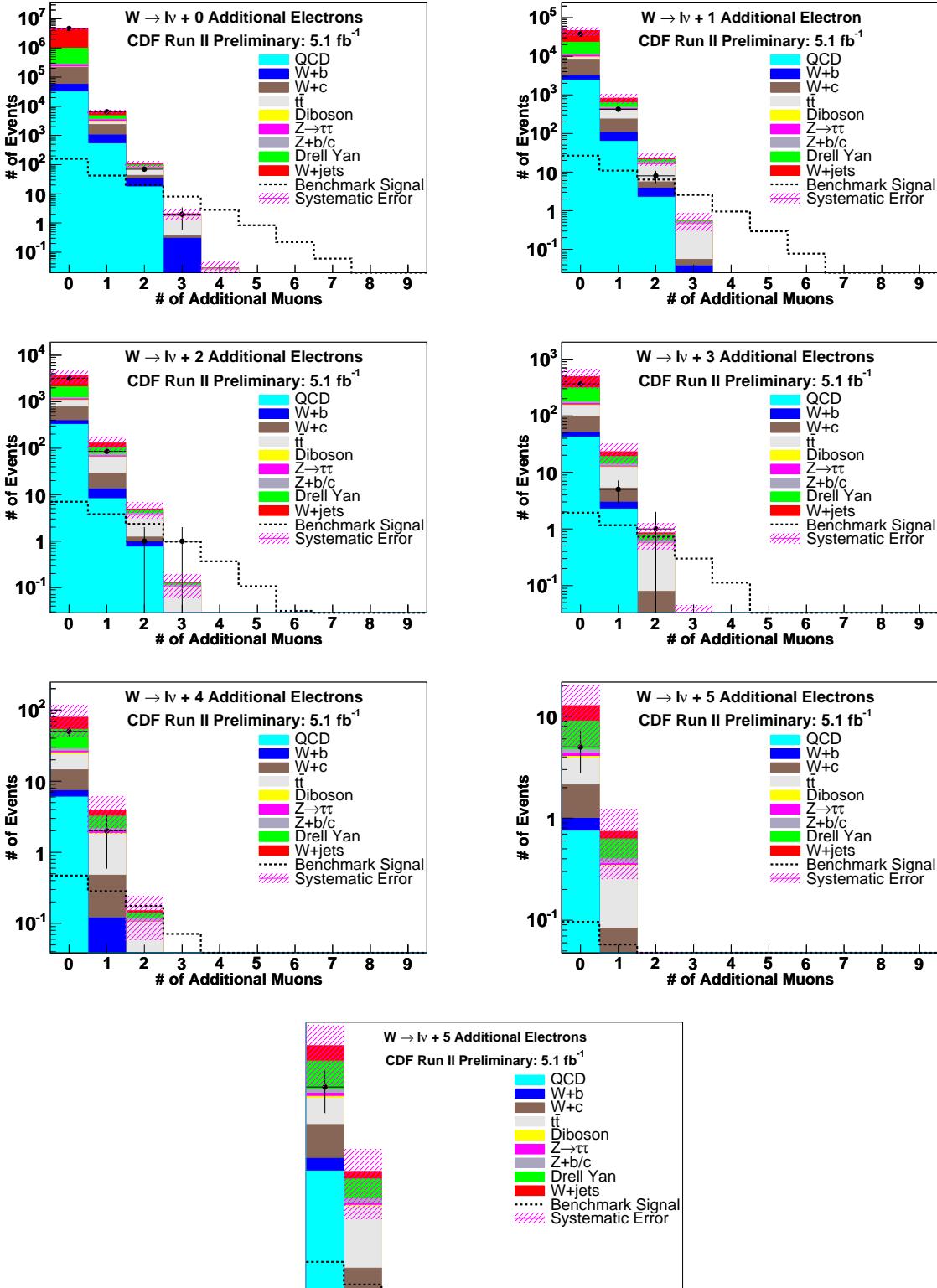


Figure 9: Muon multiplicity distribution for the W selection in bins of electron multiplicity. Both hard and soft leptons (but not the initial trigger lepton) are counted. Note that the plots combine the electron- and muon-triggered events.

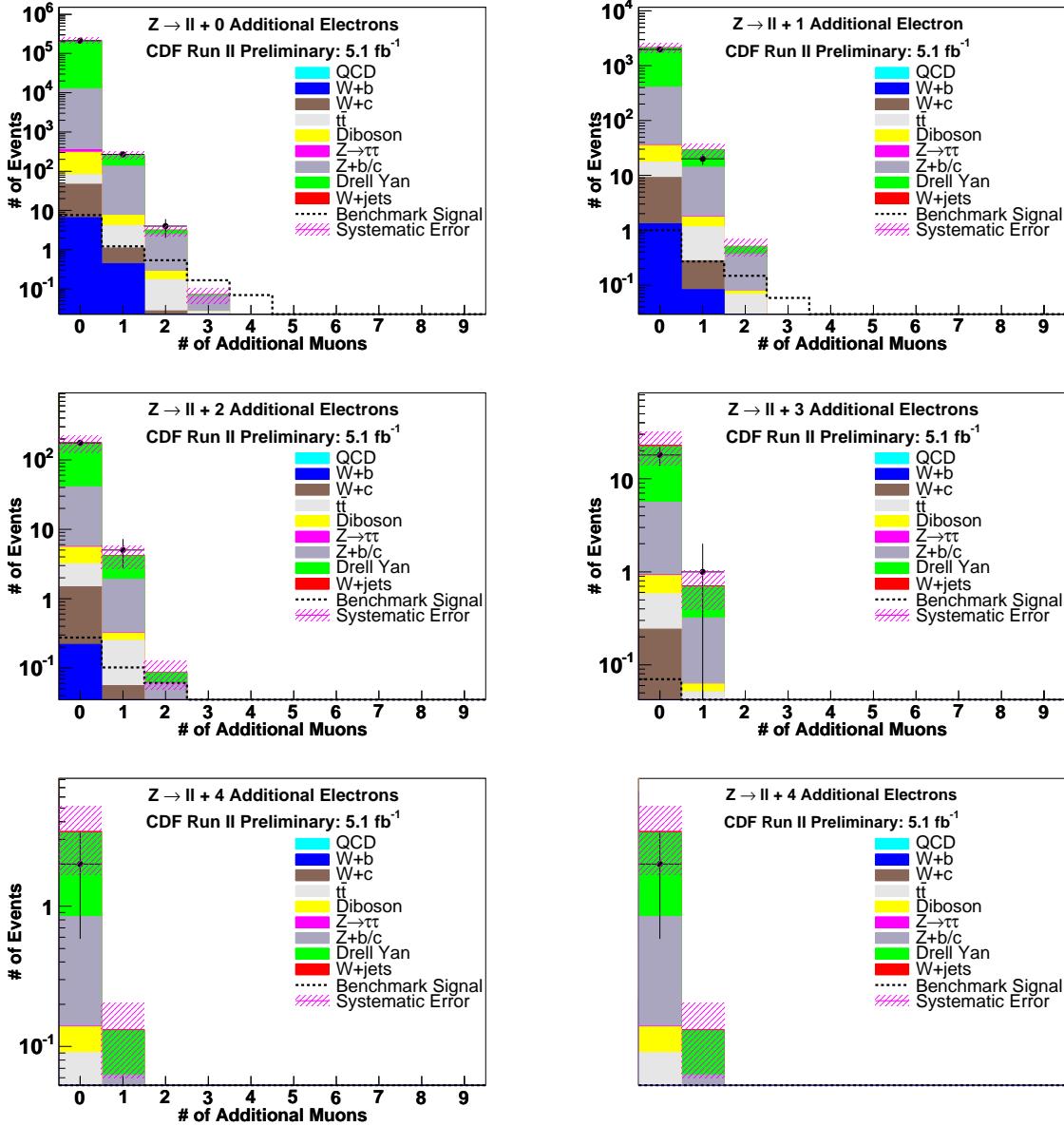


Figure 10: Muon multiplicity distribution for the Z selection in bins of electron multiplicity. Both hard and soft leptons (but not the initial trigger leptons) are counted. Note that the plots combine the electron- and muon-triggered events.

References

- [1] R. Barate *et al.*, Phys. Lett. B.**565**, 61 (2003).
- [2] R. Dermisek and J. F. Gunion, Phys. Rev. Lett. **95**, 041801 (2005); R. Dermisek and J. F. Gunion, Phys. Rev. D. **75**, 075019 (2007).
- [3] B. Bellazzini, C. Csaki, A. Falkowski, and A. Weiler, Phys. Rev. D **80**, 075008 (2009).
- [4] L. M. Carpenter, D. E. Kaplan and E. J. Rhee, Phys. Rev. Lett. **99**, 211801 (2007).
- [5] M. J. Strassle and K. M. Zurek, Phys. Rev. Lett. B **651**, 374 (2007); T. Han, Z. Si, K. M. Zurek, and M. J. Strassler JHEP **0807**, 008 (2008).
- [6] O. Adriania *et al.* [PAMELA Collaboration], Nature **458**, 607 (2009); F. Aharonian *et al.* [H.E.S.S Collaboration], Phys. Rev. Lett. **101**, 261104 (2008); A. A. Abdo *et al.* [Fermi LAT Collaboration], Phys. Rev. Lett. **102**, 181101 (2009).
- [7] N. Arkani-Hamed, D. P. Finkbeiner, T. R. Slatyer and N. Weiner, Phys. Rev. D **79**, 015014 (2009); P. Meade, M. Papucci, A. Strumia, and T. Volansky, arXiv:0905.0480 [hep-ph]; M. Pospelov and A. Ritz, Phys. Lett. B **671**, 391 (2009); I. Z. Rothstein, T. Schwetz and J. Zupan, JCAP **0907**, 018 (2009); C. Cheung, J. T. Ruderman, L. T. Wang and I. Yavin, Phys. Rev. D **80**, 035008 (2009); A. Katz and R. Sundrum, JHEP **0906**, 003 (2009).
- [8] J. T. Ruderman and T. Volansky, arXiv:0908.1570 [hep-ph]; X. Chen, JCAP **0909**, 029 (2009); J. Mardon, Y. Normura and J. Thaler, Phys. Rev. D **80** 035013 (2009).
- [9] A. Falkowski, J. T. Ruderman, T. Volansky and J. Zupan, JHEP **1005**, 077 (2010); A. Falkowski, J. T. Ruderman, T. Volansky and J. Zupan, Phys. Rev. Lett. **105**, 241801 (2010).
- [10] T. Junk, NIM A434, p. 435-443 (1999)